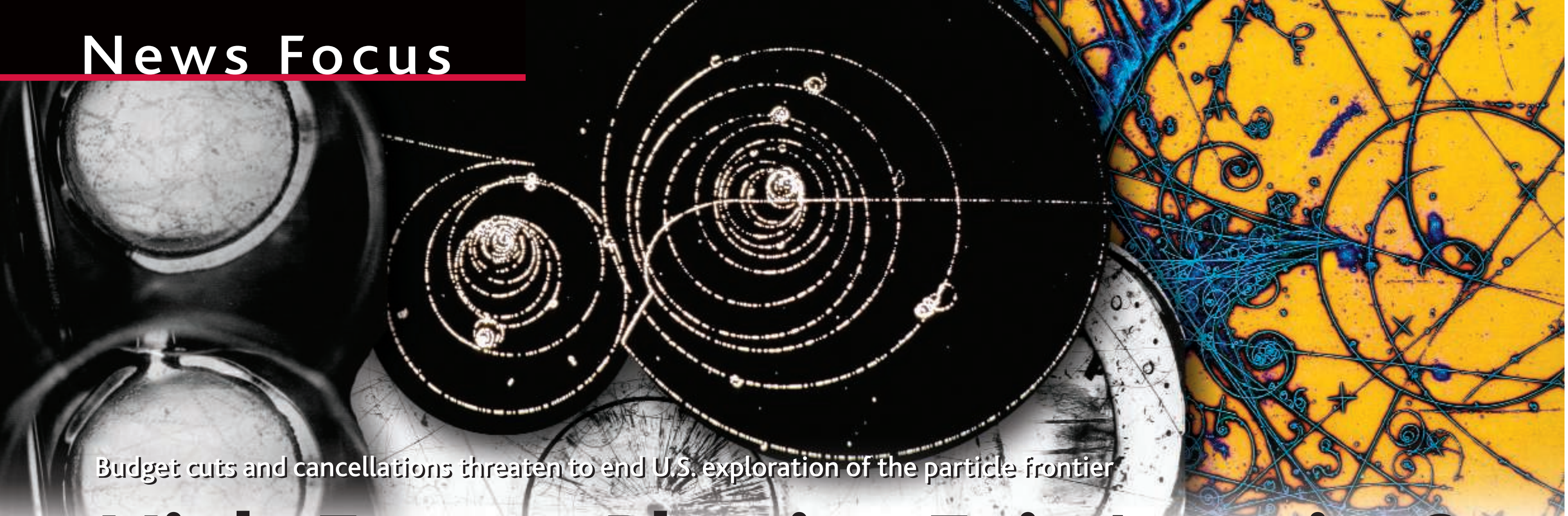


Budget cuts and cancellations threaten to end U.S. exploration of the particle frontier

High-Energy Physics: Exit America?

Monday, 7 February, was a grim day for the Fermi National Accelerator Laboratory (Fermilab). "You wake up, you go to a presentation, and you find out you're dead," says Fermilab physicist Joel Butler. Butler is co-spokesperson of an experiment known as BTeV—a multimillion-dollar project that would allow scientists to study the properties of the bottom quark. But that Monday, when the new Secretary of Energy Samuel Bodman took to the podium to announce the department's budget request for 2006, BTeV scientists were horrified to discover that their project had been canceled.

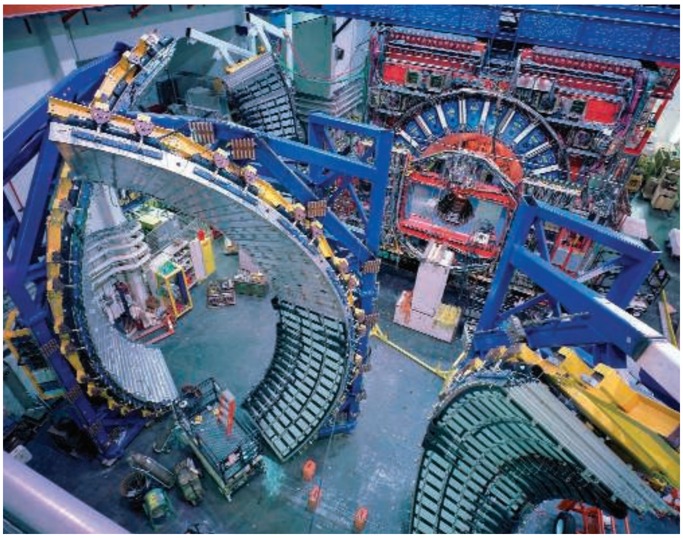
The decision—which is unlikely to be reversed by a Congress that doesn't have extra money to spend—sent ripples throughout the high-energy physics community. BTeV was the only planned project to study the physics of heavy fundamental particles at Fermilab, which is rapidly becoming the last of what was once a handful of U.S. labs devoted to the study of high-energy physics. Even under the most sanguine projections, the chances are good that no traditional accelerator experiments will be running on U.S. soil after 2010. And if a new linear collider that the Department of Energy (DOE) is gambling heavily on never materializes, the Nobel-filled record of U.S. achievements in high-energy physics could be consigned to history.

"The U.S. program is very weak looking to the future," says Michael Witherell, the outgoing director of Fermilab in Batavia, Illinois. "It's something we have to think very hard about: Is the U.S. getting out of that game?"

Heavy reality

Just as microbiology has its microscopes, high-energy physics has its accelerators. And the bigger the machine, the better physicists can see into the subatomic world.

Particle accelerators are machines that turn energy into matter. Using powerful magnetic fields, they force subatomic particles such as electrons or protons to move faster and faster until they approach the speed of light. When those particles smash into a target, they dump that energy in a sudden flash—and, in that instant, particles leap into existence out of the vacuum, born of the pure energy of the collision. As those particles interact and decay, they leave behind a shower of debris. Physicists root through those debris to figure out what, precisely, took place; the curling and branching trails of particles skittering away from the collision reveal the nature of the exotica that were brought to life for a fraction of a second.



Swan song? Fermilab's Tevatron, due to shut down around 2010, could be the last large particle accelerator in the United States.

But the exotica you can create are limited by the amount of energy your accelerator can dump into a small space. (In fact, high-energy physicists describe the mass of particles with units of energy: MeV, millions of electron volts.) Broadly speaking, the more powerful your machine, the heavier and more exotic the particles you create and the deeper you look into the laws that govern matter and the forces of nature.

In the mid-1950s, the building-sized Bevatron accelerator at Lawrence Berkeley National Laboratory in California led to the discovery of the antiproton (938 MeV). By the 1970s and 1980s, accelerators no longer fit within a single building. Such an enormous accelerator at CERN, a high-energy physics laboratory created outside Geneva in the 1950s to pool Europe's scientific resources, enabled scientists to spot the W and Z particles, carriers for the weak force that weigh in at about 80,000 MeV and 90,000 MeV respectively. In 1995, Fermilab's Tevatron, roughly 1000 times more powerful than the Bevatron, discovered the top quark (174,000 MeV). And the biggest accelerator of all—the 90-kilometer proton-proton smasher called the Superconducting Super Collider—was killed off in 1993 while still under construction in Texas.

Although these projects were the flagship "discovery" experiments of particle physics, there were others that didn't rely on brute force. By looking at how particles (such as B mesons) interact at slightly lower energies, scientists can infer properties of higher-mass particles—even if they have yet to be discovered. These two types of projects and other high-energy experiments have led to a very effective description of the fundamental components of matter and the forces that affect them: the Standard Model.

But the Standard Model is incomplete, and high-energy physicists believe that they are on the edge of two major discoveries that

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will bust it wide open. The Large Hadron Collider (LHC) at CERN, the biggest accelerator in history, will come on line in 2007 or so. For a variety of reasons, physicists believe that it may well spot a particle known as the Higgs boson, a particle that will expand the Standard Model to explain why particles have mass. Many scientists also believe that the LHC will spot a "supersymmetric" particle, the first of a whole class of new fundamental particles that lie beyond the Standard Model—and that may be responsible for most of the matter in the universe. When it does, physicists hope to use the next great accelerator under consideration, the International Linear Collider (ILC), to zero in on those fresh discoveries and give theorists the ability to extend the Standard Model to a truly all-inclusive theory of matter (*Science*, 21 February 2003, p. 1171).

Yet even as high-energy physicists anticipate great discoveries in the next decade, the high-energy physics budget in the United States is dropping. This year, DOE, which funds the vast majority of high-energy physics in the United States, requested $716 million for high-energy physics, a decline of about 3% from the previous year. The cut follows years of stagnant budgets that have left labs with barely enough funding to run existing experiments, much less start new projects. "We're running at a lower level than we'd like," says Ray Orbach, head of DOE's Office of Science. "How can we run the current facilities, support current people, and at the same time have a future? That's the central question."

That future looks bleak. "There is no new money," says Robin Staffin, head of DOE's office of high-energy physics, who says that there is insufficient funding to start new projects. "Any new initiatives will have to come from redirection."

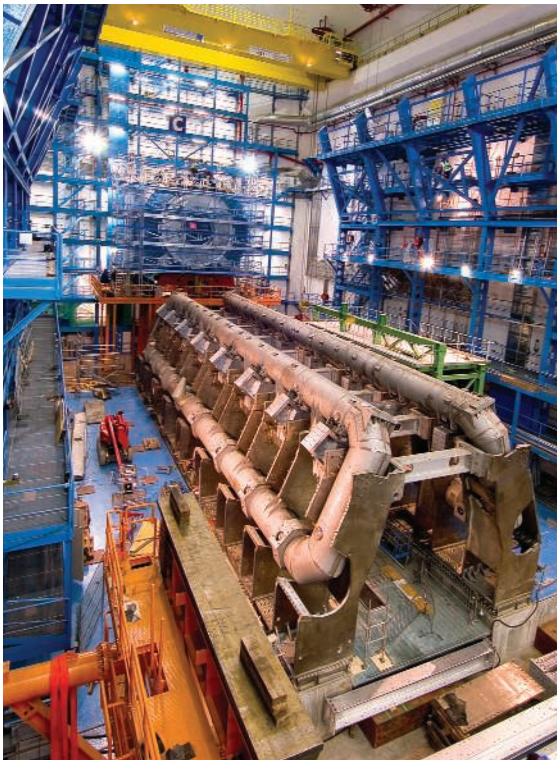
A new direction

That redirection caught BTeV scientists off guard. "I was surprised by this," says physicist Sheldon Stone of Syracuse University in New York, co-spokesperson for BTeV. "There was no advance information to either us or to the Fermilab group." Even Fermilab Director Witherell says that he didn't know about BTeV's cancellation until the day of the speech. "The first I found out was when I downloaded the budget from the Web site [that morning]," he says. "It was a shock: There was nothing to replace it, and $20 million was cut from the budget."

"It's looking very difficult in the U.S.," says Roger Forty, deputy spokesperson of LHCb, a similar B-physics experiment that will start up at CERN when the LHC turns on. "From a global perspective, it's a pity."

According to DOE officials, BTeV had to die. "We did not see in our budget how to accommodate this," says Staffin. Orbach agrees that DOE had no alternative but says the decision saddened him: "It's a downer."

The decision to cancel BTeV weakens the program at Fermilab, which will soon be the last remaining high-energy physics laboratory in the United States. Brookhaven National Accelerator Laboratory in Upton, New York, has shifted its focus to nuclear physics, although its plans to host a heavy-particle project known as RSVP recently took a hit after an apparent jump in its projected cost (*Science*, 18 February, p. 1022). The Stanford Linear Accelerator Center (SLAC), which is currently using a collider to produce B mesons, will shut down its B factory in 2008 or so to focus on generating x-ray beams for studies of chemical bonding and other high-speed phenomena on the molecular scale. "Fermilab is the future of high-energy physics in the United States," says Orbach.



Next big thing. The Large Hadron Collider in Geneva should ensure European dominance of high-energy physics.

CREDIT: CERN GENEVA

Yet Fermilab's future direction is uncertain. The Tevatron will also likely be shutting down in 2010 or so. Unless a new project comes along, after that date the laboratory will not be using its equipment to study quarks at all. And until the ILC turns on—if it ever does—Fermilab and the United States will be out of the traditional high-energy physics game. "This is the first time in my memory that there is nothing in line, no major items of equipment" being requested, says Witherell.

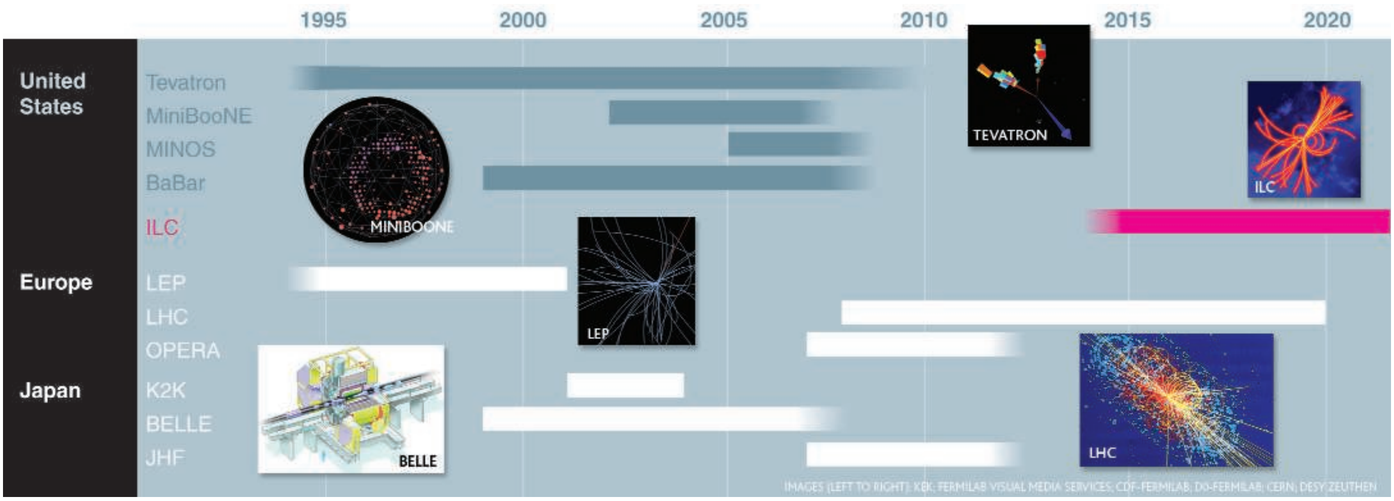
Given those realities, Orbach's pledge that DOE "will continue to support Fermilab" is less than reassuring to high-energy physicists. The support DOE has in mind would require moving away from Fermilab's traditional strengths—the physics of quarks and other heavy fundamental particles—toward areas such as neutrino physics.

In 2002, Fermilab scientists began running MiniBooNE, smashing protons from a Fermilab accelerator ring into a target. The resulting neutrinos are steered to a nearby detector in hopes of learning some of the fundamental properties of those nearly massless particles. Last month Fermilab launched NuMI/MINOS, in which a similar setup sends neutrinos to a detector in Minnesota (*Science*, 11 March, p. 1543).

Although the scientific community is excited about the new experiments—and two or three potential follow-ons to NuMI/MINOS—the shift from studying quark flavors and heavy particles to neutrinos has been an uncomfortable one for many Fermilab physicists. Even the neutrino scientists at Fermilab have their qualms. "This lab used to do so many kinds of physics," says Deborah Harris, a physicist working on the NuMI/MINOS experiment. "It's strange to put all your eggs into one basket. It's a very good basket and an important basket, but it seems strange to focus so narrowly."

Fermilab has not yet abandoned studying quarks and other heavy particles, and the Tevatron will likely run until the end of the decade. "We're going flat out," says Orbach about what he calls a "very vibrant" research program at the Illinois lab. "We're going to leave the Tevatron a burning hulk when we finish with it." Scientists at Fermilab and elsewhere in the United States are also collaborating on planned LHC experiments that will provide fresh opportunities for studying heavy particles. Furthermore, observing cosmic rays and other high-energy phenomena in the heavens might give scientists an indirect way of understanding fundamental particles, as would mineshaft experiments to find exotic dark matter.

Nevertheless, these experiments are not nearly as far-reaching (or expensive) as the accelerator-based experiments in which the United States excelled for so many decades. Combined with the new emphasis on neutrinos, DOE is steering Fermilab—and the high-energy physics community in the United States—away from its traditional strengths in accelerator physics and high-energy experimentation. "The thing I most worry about is that we're allowing an important line of our physics to atrophy because we



IMAGES (LEFT TO RIGHT): KEK; FERMILAB VISUAL MEDIA SERVICES; CDF-FERMILAB; DO-FERMILAB; CERN; DESY ZEUTHEN

Wild card. An American site for the International Linear Collider would give the U.S. a stake in future experiments—if the ambitious project ever gets built.

can't afford it," says Witherell. "It's an area that the U.S. has always been a leader in. That's a problem."

To remain active, Fermilab's Butler says, "a large number of U.S. physicists at the Tevatron are already planning to work at the LHC; they have exit strategies." But Butler isn't happy about the new venue. "This field is being outsourced," he says.

The one big hope for U.S. accelerator physics is the ILC. "We're going to go for the linear collider," says Orbach. If based in the United States, the collider would not only give high-energy physicists a machine to explore Higgs and supersymmetry physics, it would also prevent a hemorrhage of heavy-particle physicists overseas. That's an appealing prospect to federal politicians. "We want the best minds in the world coming here and not going elsewhere. That's all to our benefit," says Speaker of the House Dennis Hastert (R–IL), who attended the recent start-up of the NuMI/MINOS experiment at Fermilab. But the leader of the majority party in the U.S. House of Representatives isn't ready to make a firm commitment. "If [the ILC] fits within certain parameters, we'd like to keep it in the U.S.," Hastert says.

The biggest of those parameters is the cost, estimated by DOE at $12 billion, of which the host country would presumably pick up half. "Now we have a unified program," says Orbach. "The problem is that it's too expensive." DOE might be able to handle a project of half that size, Orbach says, but the probability of joining a $12 billion project is slim.

Dark forecast. Outgoing Fermilab director Witherell wonders whether the U.S.'s "very weak" future program marks the end of the line.

The odds are better than that, says physicist Barry Barish of the California Institute of Technology in Pasadena, who heads the ILC design group. He doesn't accept DOE's projected price tag. "There's no way you can get me to talk about cost" until the design group completes some preliminary studies, he says. "But I don't buy $12 billion."

For Butler and other physicists, the projected completion date for the ILC in the middle of the next decade is another huge obstacle. "The schedules put up are frankly incredible and don't do justice to the effort," Butler says. But a timetable that puts the ILC at the end of the next decade or beyond would leave an entire generation of physics students without access to an accelerator in the United States.

All or nothing

In an attempt to make the best of a bad situation, high-energy physicists are reprioritizing their projects—again. The High Energy Physics Advisory Panel (HEPAP), which counsels DOE and the National Science Foundation, will apparently be resurrecting its Particle Physics Project Prioritization Panel—a subcommittee that disbanded at the end of 2003 after presenting its recommendations (which included strong support for BTeV). The National Research Council is busy preparing a report, *Elementary Particle Physics in the 21st Century*, that will do a similar job from a broader perspective (as many of the committee members are from outside particle physics). The goal is an attractive, unified program that lawmakers will be able to fund.

But these efforts may be moot if the budget situation doesn't improve. "What use is a 20-year outlook if you can't build anything?" Orbach rhetorically asked HEPAP physicists, who were likely wondering about the same question. Having priorities is not equivalent to having a budget, he adds, although such a list may improve DOE's chances of getting some of its projects funded.

Some high-energy physicists fear that their problems run far deeper, however. Perhaps, they speculate, the United States no longer considers high-energy physics very important, and comments by DOE officials provide little comfort. "Where society goes, the budget also goes," says Staffin. A major discovery—like the Higgs or supersymmetric particles—could win back public support, they say. But will U.S. labs be ready to respond?

Most labs, like SLAC and Brookhaven, will have stopped research in the field. Fermilab will be concentrating on a neutrino physics program and some smaller projects, with all its study of heavy fundamental particles taking place overseas. And if Congress doesn't make room in DOE's budget for the International Linear Collider, then there may be no active U.S. high-energy physics program to take advantage of a breakthrough should it come. "It's a gamble," Orbach admits about the road DOE is taking in high-energy physics. "We're going for broke."

–CHARLES SEIFE

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